Geothermal Sessions

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Geothermal 1 — Techniques and Interpretation

Megasource EM Method for Detecting Deeply Buried Conductive Zones in Geothermal Exploration **G1.1**

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Application of the magnetotelluric method in geothermal exploration has indicated that in some geothermal areas, zones of unexpectedly high electrical conductivity occur in the crust at depths of only 5 to 10 km. Delineation of these features, which may represent the thermal roots of shallower exploitable geothermal systems, is difficult with the MT method because of the time required to make an individual sounding, and because of the complexity of interpretation of MT sounding curves when strong lateral variations in resistivity exist. The controlled source EM methods offer the possibility of more definitive delineation of anomalies associated with geothermal systems, providing that penetrations of 5 to 10 km can be obtained. One approach to reaching great depths in EM sounding is through the use of very intense sources, a procedure known as the Megasource EM method.

A Megasource EM survey was carried out in the Dixie Valley-Carson Sink area of northwestern Nevada. In this area, earlier MT surveys indicated the existence of anomalously conductive zones in the crust at depths as shallow as 5 to 10 km. The conductive zone is spatially related to the areas of most intense surface thermal activity in Dixie Valley and the adjacent Stillwater Mountains. Several apparently successful geothermal test wells had been drilled in this anomalous area. In the survey described here, an EM field was generated by passing a square wave current of 3000 A peak-to-peak amplitude along a 1 km grounded wire, providing a source moment of 3 x 10^6 amperemethers (Hence "Megasource"). The source was located on the northwest side of Carson Sink, at a distance of approximately 50 km from the target areas for exploration in Dixie Valley and south end of Carson Sink. The observation of EM fields at these distances from the source were expected to permit the determination of resistivity in the crust to depths up to 20 km. Observations of transient EM coupling using a vertical axis simulated-loop receiver were made at nearly 400 receiver locations distributed at intervals of approximately 1 km along the accessible roads in the survey area. The time interval over which the transients were recorded was from a minimum of 30 msec to a maximum of 30 sec. Many of the curves were interpreted using a one-dimensional inversion approach. The survey was successful in identifying an area where anomalously conductive rocks exist in the upper crust at depths as shallow as 7 km. This area includes locations of the successful test wells in Dixie Valley and surrounding regions. Resistivity in the anomalous zone in the upper crust is reasonably consistent, ranging from 5 to 15 Ω-m. These data might be explained by the existence of a partially moulten zone at shallow depths in the crust, but it seems more likely that the high conductivity results from extensive fracturing and a high saturation of hot water in the crust.

Experience with the EM-60 Electromagnetic System for Geothermal Exploration in Nevada **G1.2**

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Through a joint program between the Dept. of Energy/Division of Geothermal Energy and private geothermal developers, Lawrence Berkeley Laboratory (LBL) conducted controlled-source (frequency domain) EM surveys at three geothermal prospects in northern Nevada. More than 40 receiver stations were occupied in Panther Canyon (Grass Valley), near Winnemucca; Soda Lakes, near Fallon; and McCoy, west of Austin to test and demonstrate the applicability of the EM-60 system to subsurface resistivity mapping.

The EM-60 is a frequency-domain, horizontal-loop transmitter system for which we use three-component magnetic detection. Typically, we apply ± 65 A to a 100-m diameter, four-turn loop, generating a dipole moment > 10^6 MKS over the frequency range 10^{-3} to 10^2 Hz. By virtue of this large dipole moment, we made soundings at transmitter-receiver separations of up to 5 km, thus providing a maximum depth of penetration of 5 km. Recorded spectra were interpreted by means of both simple calculations done in the field and layered-model inversions calculated in the laboratory. The EM interpretations were then compared to existing geological/geophysical data sets for the purpose of combined interpretation and method evaluation.

In comparison with other electrical-electromagnetic prospecting techniques we have used, the EM-sounding method proved to be well suited to exploration for the following reasons. It provides good depth of exploration in relation to the transmitter-receiver separation, it is relatively insensitive to distant and local lateral inhomogeneities, it provides good resolution of buried conductive bodies, and it does not require frequent movement of long wires. Experience with the EM-60 system in Nevada has shown it to be an efficient alternative to dc resistivity and magnetotellurics — and possibly more cost-effective — for geothermal exploration. An average of two soundings per field day for depths of exploration up to 2 km were obtained routinely.

Results from EM-60 at Panther Canyon compare very favorably with earlier dipole-dipole resistivity surveys. Both methods adequately outlined an irregularly shaped, buried conductive body associated with a region of high heat flow, but EM-60 provided results in just over half the field time required for dipole-dipole resistivity. At Soda Lakes, 13 high-quality EM soundings were obtained from two transmitters in 6 field days under ideal field conditions. With the EM data we were able to map the depth to and inclination of a buried conductive body associated with an area of anomalous thermal gradients. In this case, the EM results confirmed an earlier MT survey interpretation and gave additional, detailed, near-surface information. At the remote and mountainous McCoy site, data interpretation was complicated because of the locally rugged terrain. By modifying existing interpretive software, we were able to calculate the effects of tilted-source dipoles and elevation differences on soundings and thus interpret data. The EM soundings discern a conductive zone (depth 200 m) at the south end of the prospect, near a location where drilling encountered water at 100 °C. In addition, EM soundings at McCoy provided information on a deep conductor below 2 km which has yet to be drilled.